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MASTER

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University of California

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PHERMEX - Pulsed High-Energy Radiographic Machine Emitting X rays[a]

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ABSTRACT

The PHERMEX facility used to provide flash radiographs of explosives and explosive-driven metal systems is described. With this facility, precision radiographs of large objects containing materials with high atomic number and high density are attainable. PHERMEX encompasses the high-current, three-cavity, 30-MeV linear electron accelerator; the 50-MHz-radio-frequency power source to drive the cavities; timing, firing, and signal detection system; and a data-acquisition system. Some unique features of PHERMEX are reliability; very intense submicrosecond bremsstrahlung source rich in 4- to 8-MeV x rays; less than 1.0-mm-diam spot size; precision determination of edges, discontinuities, and areal-mass distribution; and flash radiographs of large explosive systems close to the x-ray target.

Some aspects of the PHERMEX-upgrading program are discussed. The program will result (1) in an increased electron-beam energy to about 50 MeV, (2) the use of an electron-gun pulser that is capable of producing three time-adjustable pulses for obtaining three "radiographic" pictures of a single explosive event, (3) an increased electron injection energy of 1.25 MeV, (4) the capability for recording high-speed signals, and (5) the use of computers to assist the monitoring and control of the data-acquisition system and the PHERMEX accelerator.

[a]Work performed under the auspices of the U.S. Department of Energy

PHERMEX, which is an acronym for Pulsed High-Energy Radiographic Machine Emitting X rays, is a large flash-radiographic diagnostic facility used for the study of explosives and explosive-driven metal systems. At the heart of the facility is a 30-MeV linear electron accelerator[1-4] that produces a very intense but short burst of x rays from a thin tungsten target. With this bremsstrahlung source, precise radiograhic studies of hydrodynamic phenomena of large assemblies containing high atomic number and high-density materials is possible. Several unique features of PHERMEX are (1) the intense 30-MeV x-ray source, (2) 50 R at 1.0 m in air from a 200-ns pulse, (3) 1.0-mm spot size, (4) the ability to radiograph large explosive systems close to the x-ray target, and (5) very reliable operation and pulse-to-pulse reproducibility.

The discussion in this paper will be limited to a description of the radiographic machine as it exists at the present time and to an explanation of the upgrading program to increase the energy and intensity of the x rays, the use of a three-pulse pulser to produce three images at selectable times of a single explosive event, recording of high-speed events and signals, and the use of computers to assist in the monitoring and control of data-recording system and the PHERMEX accelerator.

This facility is one of many at the Los Alamos National Laboratory. Since the PHERMEX activities usually involve explosives, the facility is located in a remote area of the Laboratory. Figure 1 is a map of the entire complex and the insert shows in more detail the location of firing site relative to the PHERMEX-machine building, Power Control Building, and Detection Chamber. Other areas are the office building and the accelerator-development area. The photograph in Fig. 2 shows the firing site, the PHERMEX chamber, and the rf-power-control building in the background; the view is west. The PHERMEX building, which houses the accelerator and ancillary equipment, is a concrete hemi-cylindrical-shaped structure about 30 m long, 10 m wide, and 10 m high. The rounded nose at the target end is also concrete 1.5 m thick and is covered with steel matting and sandbags for protection against blast and shrapnel.

The PHERMEX machine is a standing-wave linear electron accelerator operating at an injected rf power of 13.5 MV for 3 ms. Three cylindrical resonant cavities connected in tandem and operating in the TM_{010} mode provide the energy-storage chambers for exchanging energy between the electromagnetic field and an axially injected electron beam. Figure 3 is a schematic drawing of the machine illustrating the principal features. Each cavity is 4.6 m in diameter and 2.6 m in length, corresponding to a resonant frequency of 50 MHz and a length that is slightly less than a half wavelength. The three cavities which were constructed from copper-clad steel are connected by 0.46-m-long drift sections. The cavities are located inside a steel chamber approximately 11.3 m long, 5.0 m in diameter, and about 10^5 kg in mass. Figure 4 is a view of the accelerator from the rear. The cavities are maintained at a vacuum of 10^{-7} Pa, and the outer chamber is evacuated to 10^{-3} Pa. Each cavity has six 458-mm-diam ports oriented horizontally to provide connections for injecting the rf power and to provide slugs for tuning each cavity.

The first cavity (alpha) in the accelerating chain operates at a field strength of 5 to 5.5 MV/m, the second cavity (beta) has field strengths of 6 to 7 MV/m, and the third cavity (gamma) is supplied with fields of 4 to 4.5 MV/m which is furnished by high-power 50-MHz rf amplifiers. A 350-A electron beam is injected into alpha cavity from an electron gun and is chopped into micropulses because only part of the electrons are in phase with the rf source. For instance, a 200-ns-long pulse will be chopped into 10 micropulses of electrons 20 ns apart and 3 ns wide. Figure 5 shows an oscilloscope record of these subbursts as they appear at the target end of the machine. At the exit aperture of gamma cavity, the electrons have been accelerated to a final energy of about 30 MeV with a beam current of about 125 A.

A collimating lens at the exit of gamma cavity keeps the beam confined to a diameter of 25 mm. Figure 6 is a schematic of the ejection end of the accelerator and the 10-m-long drift section including the collimating and focusing lenses. A steering magnet just beyond the collimating lens is employed to deflect the electron beam a few millimeters to better center the beam on the target. A beryllium plug with a 25-mm-diam hole collimates the beam before focusing. A lens with 0.5-m focal length focuses the beam to a 1.0-mm-diam spot onto the tungsten target after going through a 3.0-mm-diam beryllium collimator. As noted in Fig. 6, the focusing lens and target assembly are mounted outside the PHERMEX chamber in a thick steel blast shield with an expendable aluminum nose cone.

The target is a 1.75-mm-thick tungsten disk. After each pulse, the disk is rotated remotely so that the electrons do not hit the target at the same spot. The bremsstrahlung that results from stopping the electrons in the tungsten is collimated by a thick uranium plug next to the target. The x-ray beam has a highly directional radiation pattern with most of the x rays occurring in a cone with a 20° apex angle.

Electrons are obtained by applying a 600-kV pulse (individual 200-ns, 100-ns, and 40-ns pulses are available) across the anode-cathode structure of a 102-mm-diam diode gun (Pierce design). The cathode is sintered tungsten heated to a temperature of about 1200 K. Upon application of the 600-kV pulse, a 350-A beam of electrons is accelerated and confined by the anode structure. The first two magnetic lenses in tandem control the 25-mm entrance diameter and convergence angle of the electron beam into alpha cavity. Figure 7 shows the electron injector and the two magnetic lenses.

The 600-kV pulsers that drive the gun are commercially available and are manufactured by Femcor. The pulsers are Marx generators using transmission lines of a specific length as energy-storage elements to provide the desired pulse duration. A large pulse transformer and trigger-pulse amplifier deliver a very energetic spark to trigger the Femcor pulser at the appropriate time for an explosive experiment.

To achieve an electron-beam energy of 30 MeV, four amplifier chains drive alpha cavity, three drive beta cavity, and two drive gamma cavity. Figure 8 is the rf-flow diagram[5] for build-up to high power levels. To introduce rf power to the cavities, the variable frequency oscillator (VFO) shown in the diagram is gated "on" for 3 ms. Power from the amplifiers is coupled to the cavity by adjustable magnetic coupling loops in the cavity ports. The electromagnetic fields reach steady-state amplitudes in about 1.5 ms. During operations, the cavities are sampled for amplitude and phase of the fields and, if these parameters are satisfactory, a signal is generated which eventually triggers the electron gun.

Each final amplifier shown in Fig. 9 supplies approximately 1.5 MW of rf power to the cavities, and the total dc plate power demand for the nine amplifiers is 27 MW during each driving period. This dc power is derived from nine 100-μF capacitor banks, one for each amplifier. The rf power from each final amplifier is supplied by an RCA 6949 shielded grid beam triode.

Precise frequency tuning and phase adjustment are necessary to provide the correct parameters for optimum electron acceleration. Frequency tuning is accomplished by setting the variable frequency master oscillator and frequency multiplier to 49.9472 MHz and then dual-bellows tuning slugs in alpha, beta, and gamma cavities are adjusted so that each cavity resonates with the drive frequency. The rf energy generated by each of the nine amplifiers is transferred to the three cavities by large-diameter transmission lines having electrical lengths that are integral multiples of a half wavelength. The diameter of the outer conductor of each 60-Ω coaxial line is 355 mm and the inner conductor is 127 mm in diameter. Finally, coupling the rf energy to the azimuthal magnetic fields in the cavities is achieved through adjustable loops at the ends of the transmission lines.

An important phase of the PHERMEX facility is the ability to produce radiation and to detonate an explosive charge at the desired time, and to record various signals. The timing and firing electronic equipment is housed in the Detection Chamber, which is interconnected with the Power Control Building and PHERMEX Chamber. Two principal functions are carried out from the Detection Chamber. One is the tiggering and the monitoring chains needed to detonate the shot and to activate the electron gun for generation of radiation. The second function is to record the time and amplitude of the radiation pulse from a suitable x-ray detector and the signals from other diagnostics associated with the experiment.

A block diagram of the triggering chain necessary to radiograph an event is illustrated in Fig. 10. The chain begins with a "start" pulse from the master pulser. At this time each rf power channel energizes the cavities causing the fields to grow approximately as shown in the field (E) vs time (t) plot shown in Fig. 10. A PHERMEX Ready Fire (PRF) trigger is sent to the systems trigger generator to fire the detonators and the explosive. A trigger is sent from the firing set through a delay unit to the electron-gun pulser producing radiation at the desired time to radiograph the hydrodynamic event. The radiation signal is displayed on recording equipment for accurate timing information.

The signals from other diagnostics, such as contactor pins, piezoresistive pressure gauges, and quartz gauges attached to the experiment are recorded by a variety of high-speed digital and analog electronic devies. In addition, most of these devices are interfaced with a computer system that has the capability of storing data on disks or tape, maniuplation of the data by resident codes, and print-out of the information.

With the radiation levels obtainable from PHERMEX, radiographic recording of an explosive event can easily be achieved with industrial x-ray films, such as Kodak X-ray Film AA and KK (SO-142) with lead screens. Figure 11 represents the radiographic geometry used for many explosive experiments. Target protection is also shown in this illustration. Since the data are recorded on x-ray film, a blast- and shrapnel-proof cassette must be used. Two types of cassettes are used: one is a hollow aluminum cone capable of taking 355-mm-diam film, and the other is a 560-mm by 710-mm rectangular cassette. Various thicknesses of aluminum are used in front for protection. These cassettes can satisfactorily protect film from the effects of about 30 kg of explosive with the film plane as close at 900 mm to the charge center.

Several film-screen combinations may be used in one film package to record the wide latitude of the transmitted radiation intensity that is encountered in an experiment. For example, a typical film-screen combination might include one Kodak KK film intensified with two 1-mm-thick lead screens, one Kodak AA film with two 1-mm-thick lead screens, and one Kodak KK film with one 1-mm-thick lead screen. Actually, a number of film-screen combinations are used by the experimenter.

The resolution of the PHERMEX machine when using a typical shot geometry varies from 0.3 mm to 1.0 mm and is illustrated in Fig. 12. Shown is a 6-mm-thick tungsten resolution plate with square teeth of a different period machined on each edge--4mm, 3 mm, 2 mm, and 1 mm. The 1-mm period is easily resolved on the actual radiograph.

Figures 13 and 14 summarize the PHERMEX machine and electron-beam characteristics as they are today. Some of the characteristics are not as stated above because of the upgrading programs.

Currently, a program is in progress to upgrade and enhance the capabilities of PHERMEX. Figure 15 is a summary of the improvements, and only a few will be discussed in the following text. This program consists of installing a three-pulse pulser to the electron source to provide three "radiographs" of a single explosive experiment at timed intervals. This capability will require the development of high-speed electro-optical cameras to provide three-frame detection. A second part of the program is installing all new high-power final amplifiers so that sufficient power is delivered to the cavities to accelerate the increased total electric charge injected in bunches at higher voltages. Capacitor banks will also be added to double the energy storage for the final amplifier. This stored-energy increase is needed to minimize the energy depletion in the cavities during the time span of the multiple pulses. The third phase of the program includes the installation of a system of magnetic lenses to collimate and focus the higher energy electron beam, the installation of anode-coupling loops to allow more efficient transfer of the rf power from the amplifiers to the cavities, and the installation of modern electronics for a data-acquisition system with nanosecond time resolution and for computer monitor and control of timing and firing operations in the Detection Chamber and computer monitor and control for operation of the PHERMEX machine.

The three-pulse pulser that will replace the pulsers now used on PHERMEX was developed by Physics International. Features of the triple pulser are (1) three pulses each 40 ns long programmed to have separation times between pulses as short as 200 ns and as long as 40 μs, (2) the three pulses can be merged to form a single pulse 150 ns long, and (3) the pulse amplitude is variable between 600 and 1200 kV to provide a choice of energies applied to the electron source. The pulser consists of three Blumlein sections mounted in tandem, each connected to a Marx generator. Figure 4 shows a portion of the pulser. At the desired time, the Marx unit charges the front Blumlein causing the formation of the 40-ns pulse which in turn is applied to the injector. The application of the second and third pulses to the electron gun is accomplished by switching, at the desired time, the appropriately charged Blumlein section to the preceding sections, which effects completion of the transmission-line circuit for each pulse to the electron gun. Trigger pulses for the Marx units will originate from the Detection Chamber at times dictated by the experiment. The benefits of three flash-radiograhic observations from one explosive experiment provided by three programmable x-ray bursts are (1) more useful data per experiment than from three experiments, (2) better data because experiment-to-experiment variations are eliminated, (3) the time resolution will be improved by a factor of five, (4) and the space resolution will improve because of less

The amplifier assemblies consists of EIMAC rf power tetrode tubes (X-2159) installed in cans along with tank circuits compatible with 50-MHz operating frequency. In addition, low-power amplifiers are connected to the grid and screen to properly drive the final amplifiers. The final amplifiers will be located very close to the cavities reducing the length of the rf-transmission lines from the long lines now in use. The plate of each high-power amplifier tube will be connected to a capacitor bank that is capable of storing twice the electrical energy now in use. The cavities will then have double the rf energy with which to minimize the energy slump over the time the electron beam is being accelerated. Large changes in stored rf energy cause large variations in beam energy, resulting in poor focusing of the beam onto the target. The new rf amplifiers will double the power, 1.5 MW to 3.0 MW, delivered to the cavities, which in turn will increase the electron-beam energy to about 50 MeV. With a modest increase in injected current, the x-ray-flux output will be 100 R for each 40-ns burst or about 400 R for a 150-ns pulse width.

An essential part of the three-pulse capability is the detection and recording of the three "radiographic" images. The path taken to date is to replace the x-ray film now used to record the single-pulse image with a fluorescent screen. The image produced on the screen by the single 40-ns-long x-ray burst will be recorded by a high-speed camera. There would be one camera for each x-ray pulse, and the operation of each camera would be synchronized with the time of each radiation burst. The generalized setup for multiple-pulse detection is shown in Fig. 16 (only one of three cameras is shown). At present, either liquid (NE224) or a solid plastic (NE102) scintillators are used to convert the x-ray information to visible light. The decay time of these scintillators is less than 3 ns so, in principle, pulses spaced only 20 ns apart can be recorded. A set of cameras based on the ITT-F4113 proximity-focused image-intensifier tube has been built and tested. The image tube has a resolution of approximately 14 line pairs per millimeter (lp/mm) over its 40-mm-diam field when operated under conditions at PHERMEX. The overall resolution of the system for x-ray detection is 1 to 2 mm at the object plane.

Currently, an electrographic camera-and-detector system is under development from the design of Dr. Paul Griboval of the Astronomy Department of the University of Texas at Austin. The general characteristics of this detector are (1) 60-mm-diam format, (2) 150- to 200-lp/mm resolution, (3) less than 5-μm distortion, (4) the $CsSb_3$ photocathode has a quantum efficiency of 15% to 20% and uniformity is better than 2%, and (5) electron energy is 30 to 60 kV. The electron-sensitive film, which has the same emulsion used for electron microscopes, employed with this detector has a very low base density of approximately 0.05 and is linear in response to a density of 4.0. Some preliminary tests of the camera in the nonpulsed mode of operation demonstrated the superiority of the detector over the image-tube camera. The lenses used with these cameras have a 150-mm-diam front aperture. The lens-to-fluorescent distance is nominally 2.25 m with a 75-mm-thick window being used for blast protection. In addition, a 90° turning mirror is placed in the optical path so that the cameras will be out of the x-ray beam. The cameras, alignment-and-focusing apparatus, and associated electronics will be located inside a large blast- and shrapnel-proof chamber, shown in Fig. 2. In an explosive experiment, the fluorescent screen, turning mirror, and light-tight box extending from the protective chamber will be destroyed.

The PHERMEX Detection Chamber contains the electronics for controlling and measuring all timing associated with an explosive experiment as well as recording signals from other diagnostics related to the experiment. Upgrading the electronics in the Detection Chamber has been an important replacement of obsolete vacuum tubes and relay-based firing-control and interlocking circuitry with transistor-transitor logic (TTL) circuitry. This has resulted in improved reliability and easier maintenance. All 30-MHz-band-width vacuum-tube oscilloscopes have been replaced with transient-waveform digitizers. The bandwidths of the digitizers range from 2 MHz, used for recording pressure transducers, to 500 MHz, used to record the radiation monitor. In addition, a 500-MHz signal cable and patching system replaced the old system. Further, a 40-channel digital time-interval counter with 100-ps response replaced the raster-oscilloscope timing system. A digital computer system was installed to facilitate calibrating the waveform digitizers and monitoring the status of the Detection Chamber functions and to store the recorded data from the digitizers and time-interval counters on magnetic tape. Digital delay generators with 10-ns resolution and pulse boosters using modern solid-state technology have replaced the old triggering system which used analog delay units and thyratron boosters. An important feature of the improvement program was the effort to electrically isolate the Detection Chamber from the noise generated by the PHERMEX machine. All signals between the Detection Chamber and the accelerator are coupled either with optical fibers or with pulse transformers. This isolation effectively removes common electrical ground connections between the two chambers. Further electrical isolation is accomplished by means of an uninterruptable power supply which separates the alternating-current (ac) power of the Detection Chamber from PHERMEX.

A final area for upgrading is the installation of a distributed computer system in the PHERMEX Control Room to assist the operator in monitoring the numerous parameters of the accelerator. The system is composed of a host computer that communicates with 15 satellite computers over optical fibers. The satellite computers operate physically close to the circuitry they monitor and up to 100 m from the host computer. Abnormal conditions detected by the satellite computers are communicated to the host computer which in turn displays the information on a color-television display for the operator. The computer-monitoring system can simultaneously monitor 200 dc-voltage levels and 140 waveforms. This system will greatly increase recognition of faults and will provide automatic storage of accelerator data which can be used to determine accelerator-performance trends.

The culmination of the upgrade program will greatly expand the capabilities of the PHERMEX facility. Postupgrade machine and electron-beam characteristics are listed in Figs. 13 and 14. With operating computer-monitoring systems in the Detection Chamber and in the PHERMEX Control Room, the conducting of an experiment will be easier, will provide more data, and will produce more flux.

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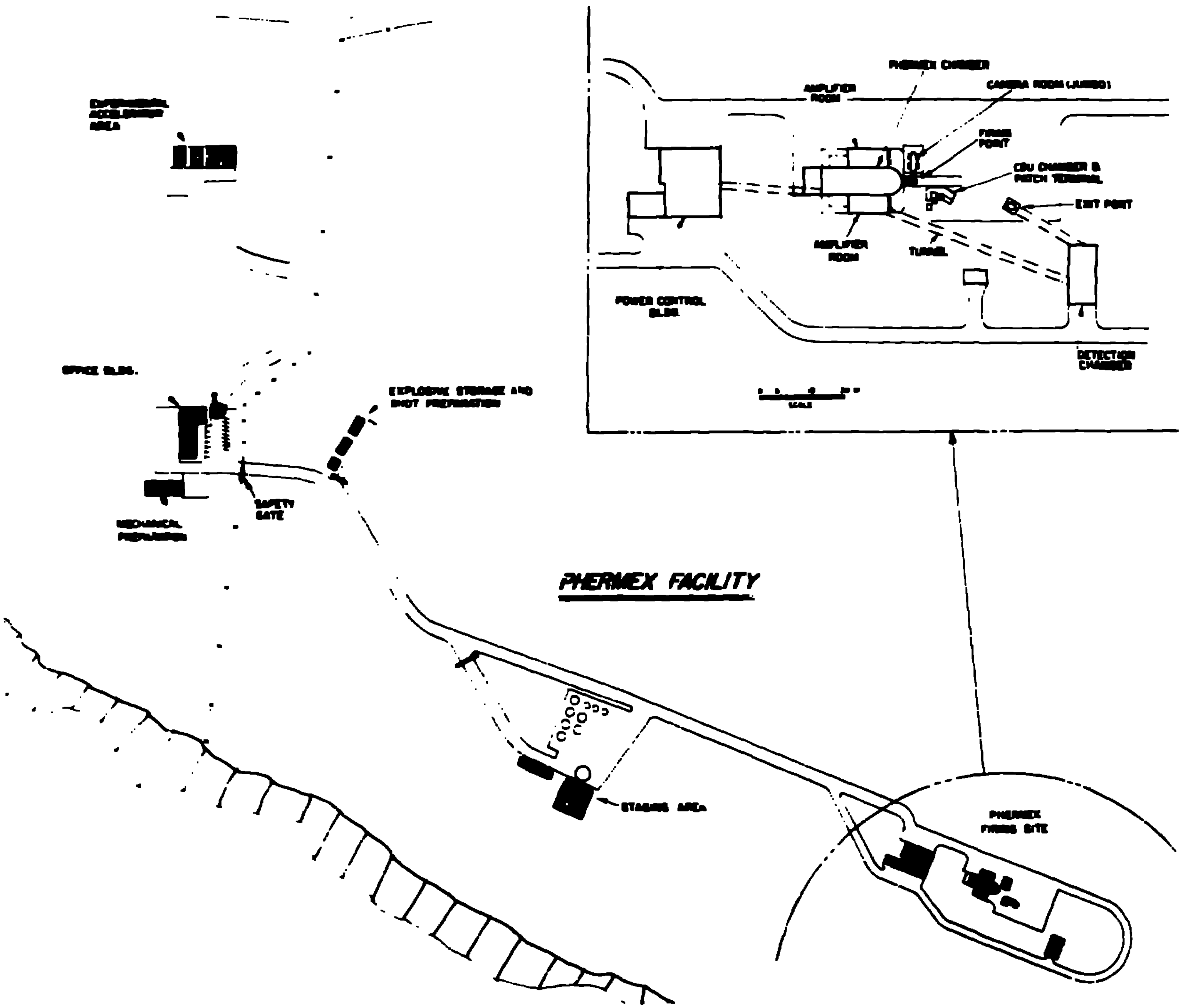
FIGURE CAPTIONS



PHERMEX FACILITY
EXPLOSIVE STORAGE AND SHOT PREPARATION
SAFETY GATE
OFFICE BLDG.
STAGING AREA
AMPLIFIER ROOM
EXIT PORT
TUNNEL
POWER CONTROL BLDG.
DETECTION CHAMBER

Fig. 1

Fig. 2

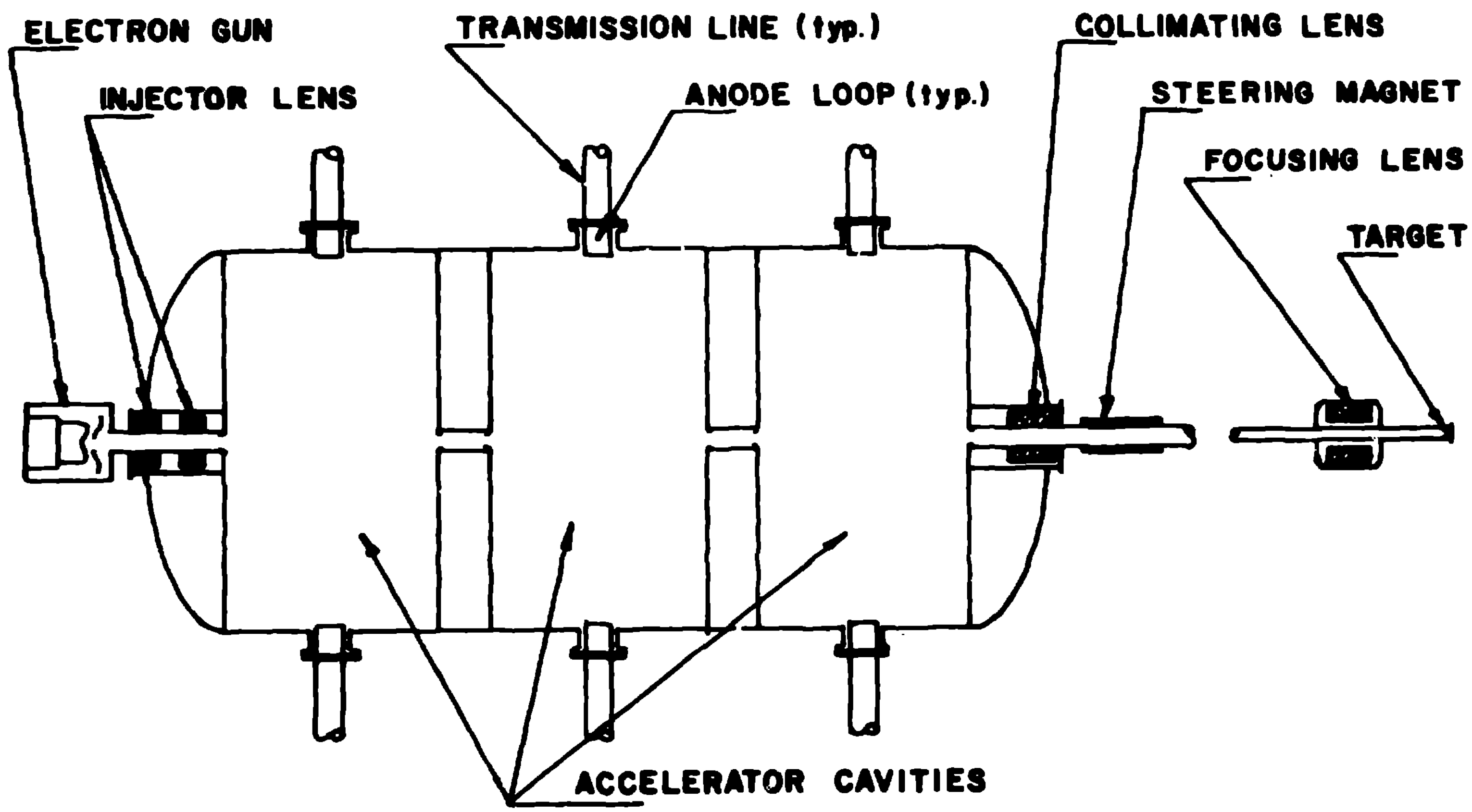

ELECTRON GUN
INJECTOR LENS
TRANSMISSION LINE (typ.)
ANODE LOOP (typ.)
COLLIMATING LENS
STEERING MAGNET
FOCUSING LENS
TARGET
ACCELERATOR CAVITIES

Fig. 3

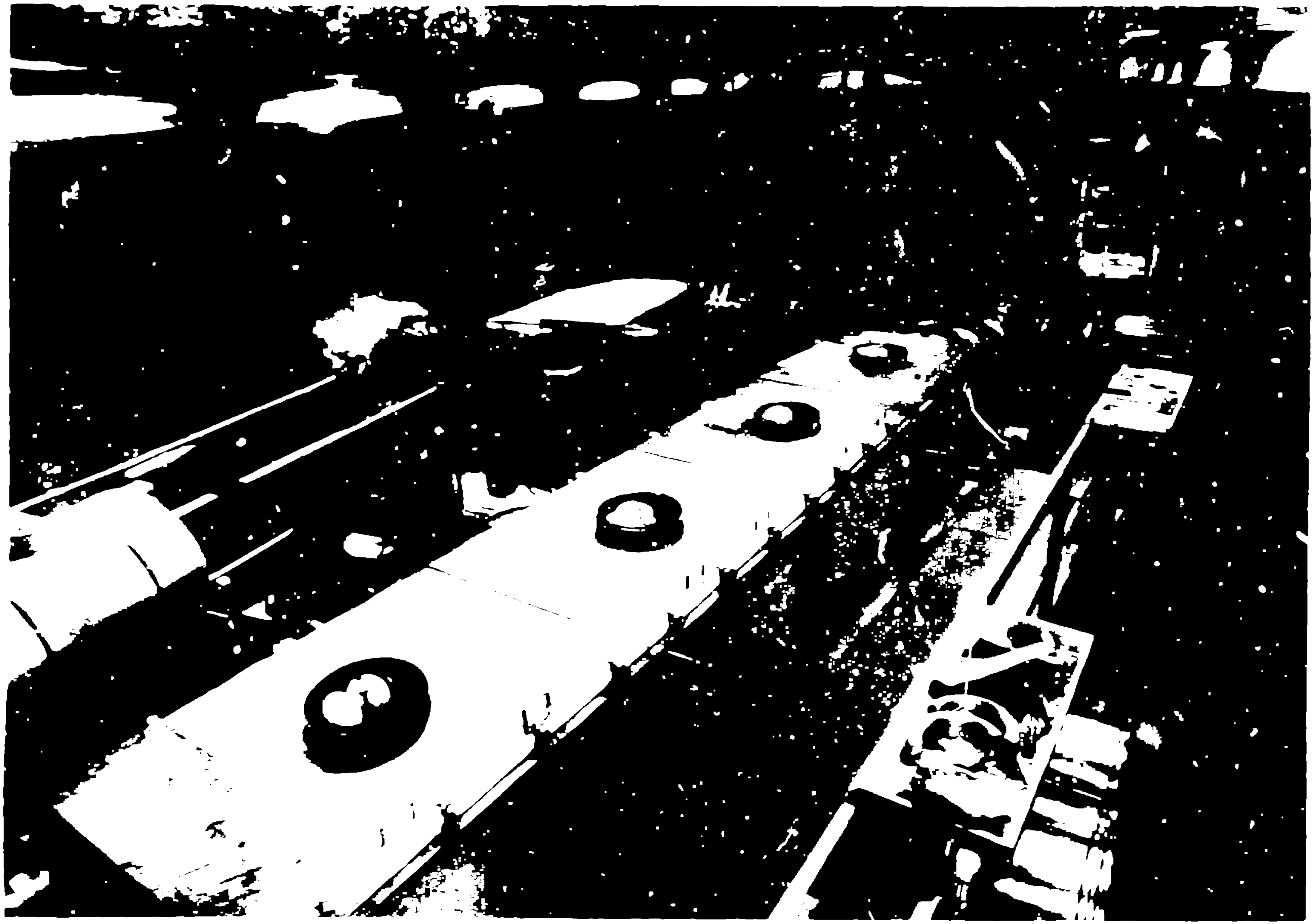


Fig. 4

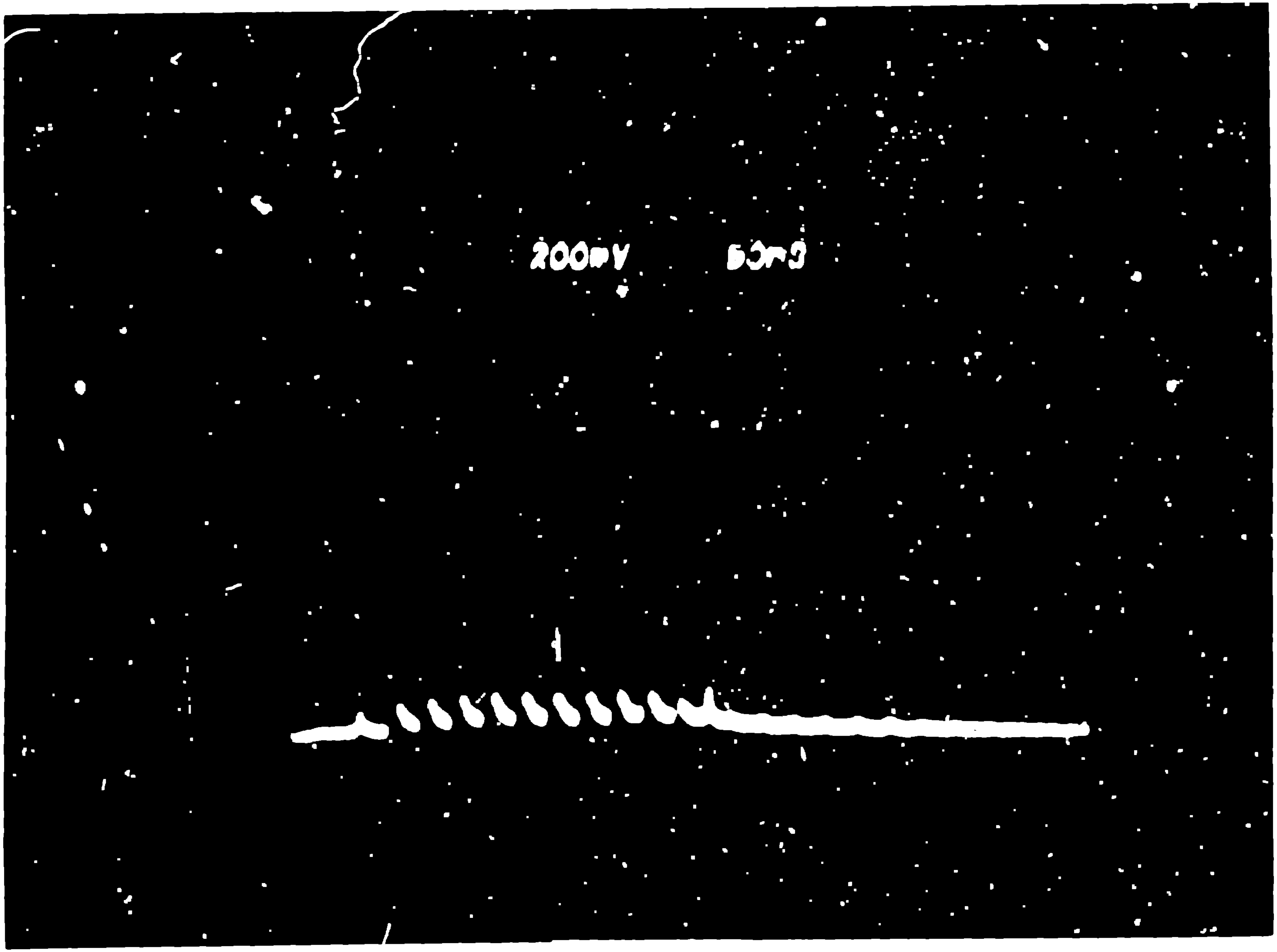


Fig. 5

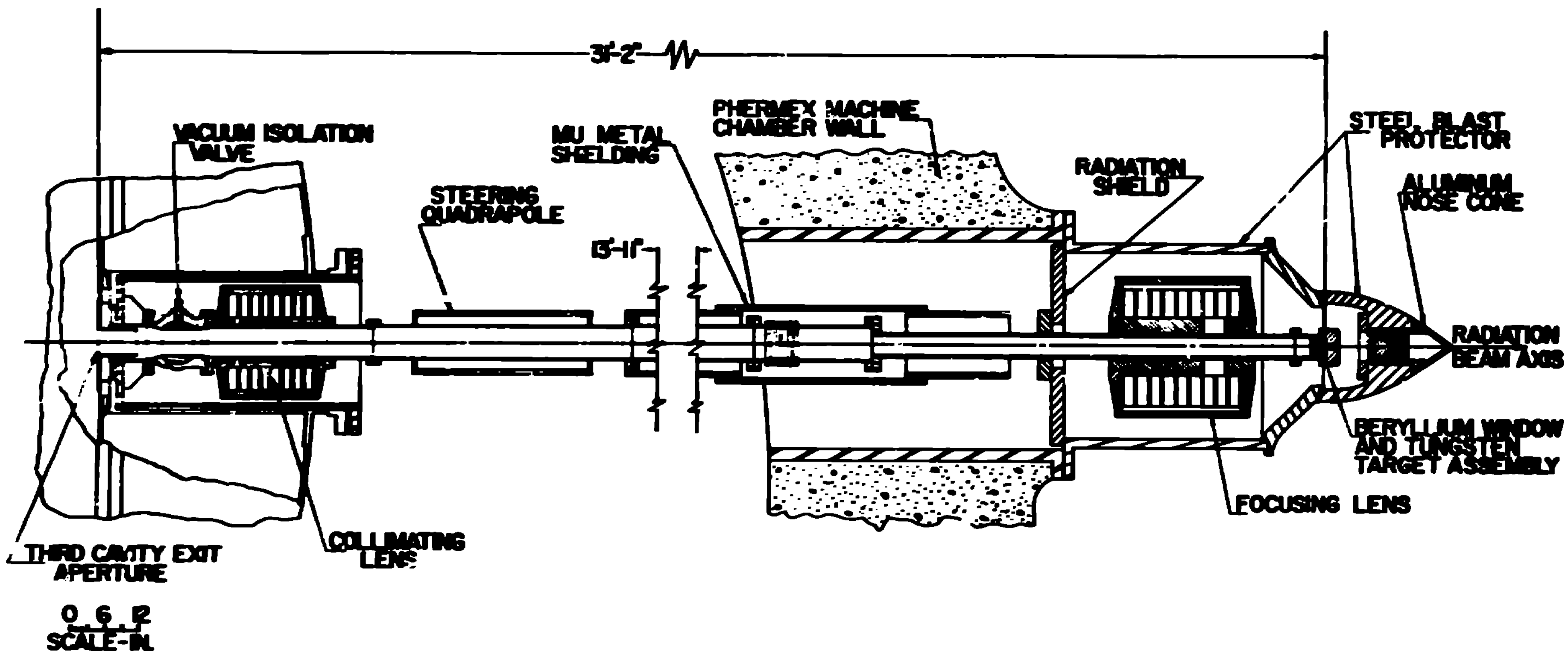

31'-2"
VACUUM ISOLATION VALVE
STEERING QUADRAPOLE
13'-11"
MU METAL SHIELDING
PHERMEX MACHINE CHAMBER WALL
RADIATION SHIELD
STEEL BLAST PROTECTOR
ALUMINUM NOSE CONE
RADIATION BEAM AXIS
BERYLLIUM WINDOW AND TUNGSTEN TARGET ASSEMBLY
FOCUSING LENS
COLLIMATING LENS
THIRD CAVITY EXIT APERTURE
0 6 12
SCALE-IN.

Fig. 6

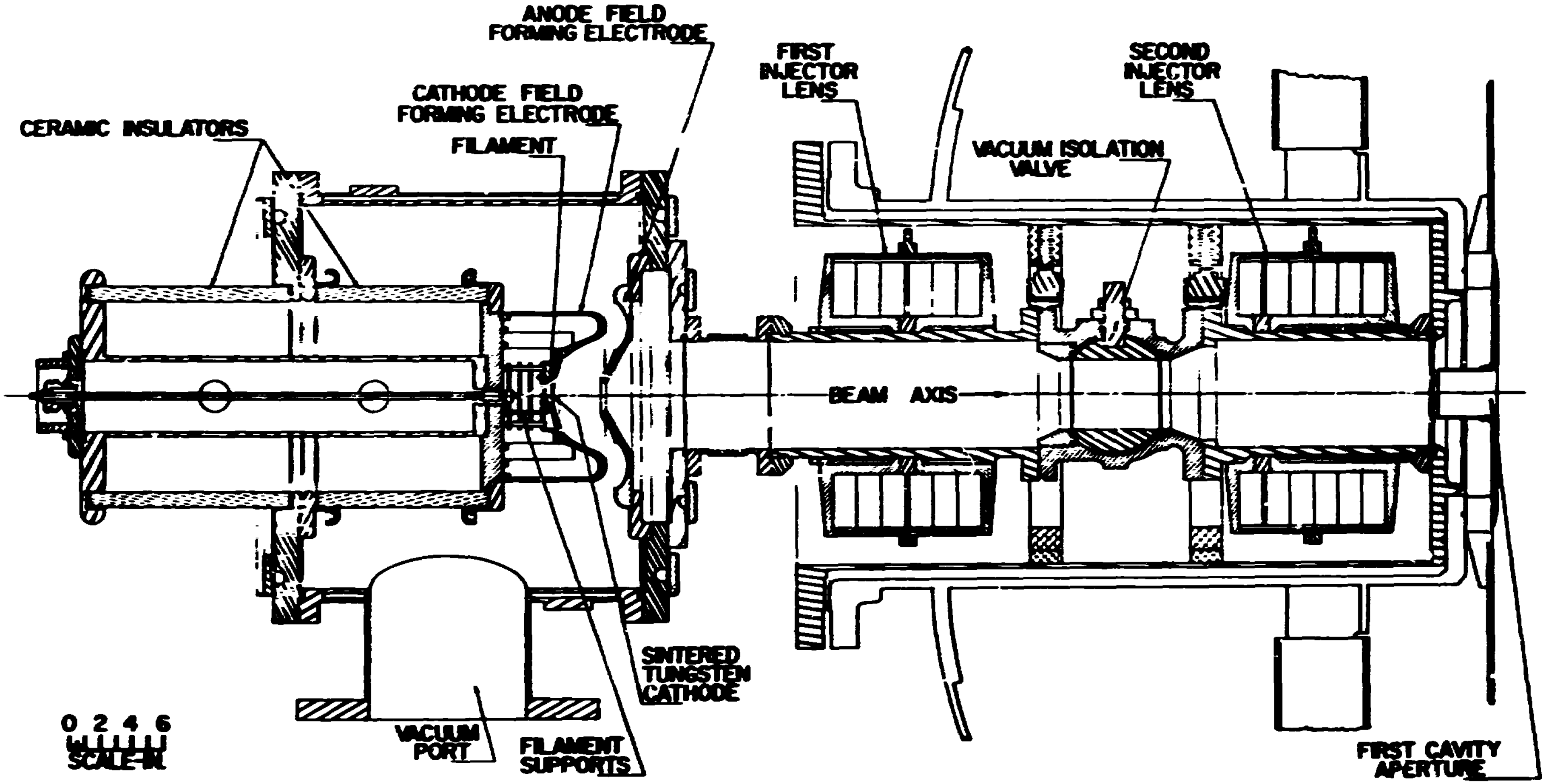

ANODE FIELD FORMING ELECTRODE
CATHODE FIELD FORMING ELECTRODE
FILAMENT
CERAMIC INSULATORS
FIRST INJECTOR LENS
VACUUM ISOLATION VALVE
SECOND INJECTOR LENS
BEAM AXIS
SINTERED TUNGSTEN CATHODE
0 2 4 6
SCALE-IN.
VACUUM PORT
FILAMENT SUPPORTS
FIRST CAVITY APERTURE

Fig. 7

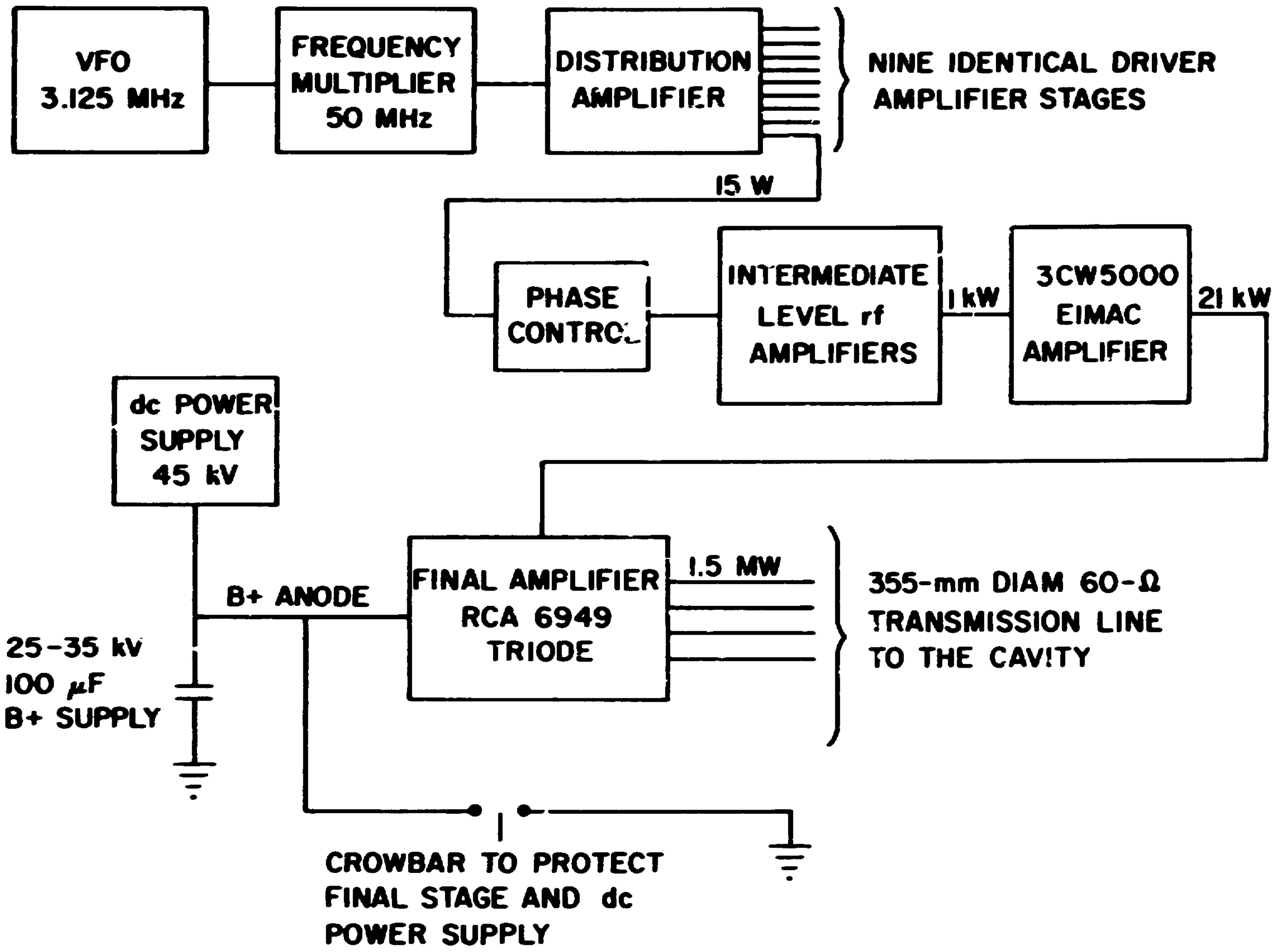

VFO
3.125 MHz
FREQUENCY
MULTIPLIER
50 MHz
DISTRIBUTION
AMPLIFIER
NINE IDENTICAL DRIVER
AMPLIFIER STAGES
15 W
PHASE
CONTROL
INTERMEDIATE
LEVEL rf
AMPLIFIERS
1 kW
3CW5000
EIMAC
AMPLIFIER
21 kW
dc POWER
SUPPLY
45 kV
B+ ANODE
FINAL AMPLIFIER
RCA 6949
TRIODE
1.5 MW
355-mm DIAM 60-Ω
TRANSMISSION LINE
TO THE CAVITY
25-35 kV
100 μF
B+ SUPPLY
CROWBAR TO PROTECT
FINAL STAGE AND dc
POWER SUPPLY

Fig. 8

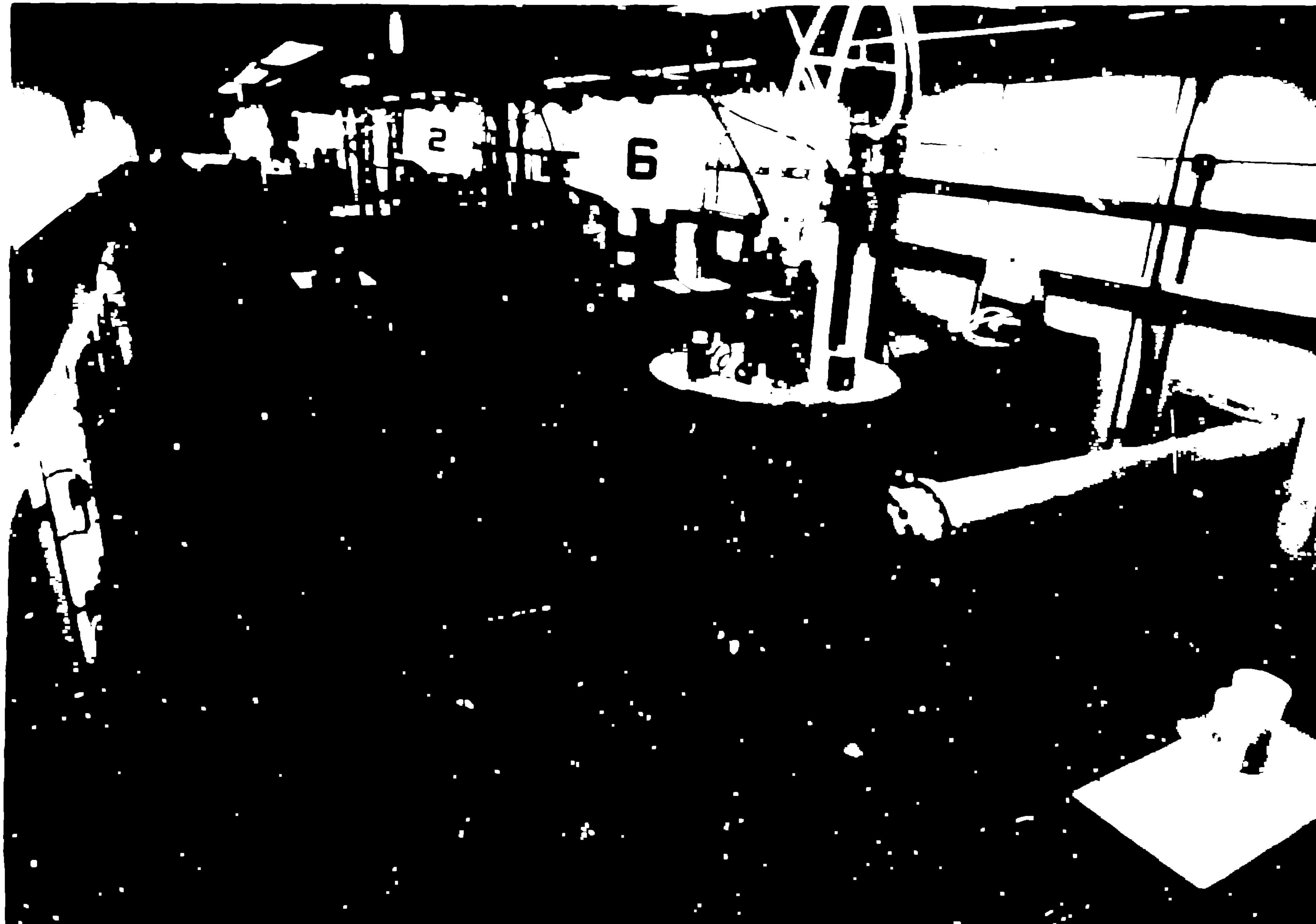
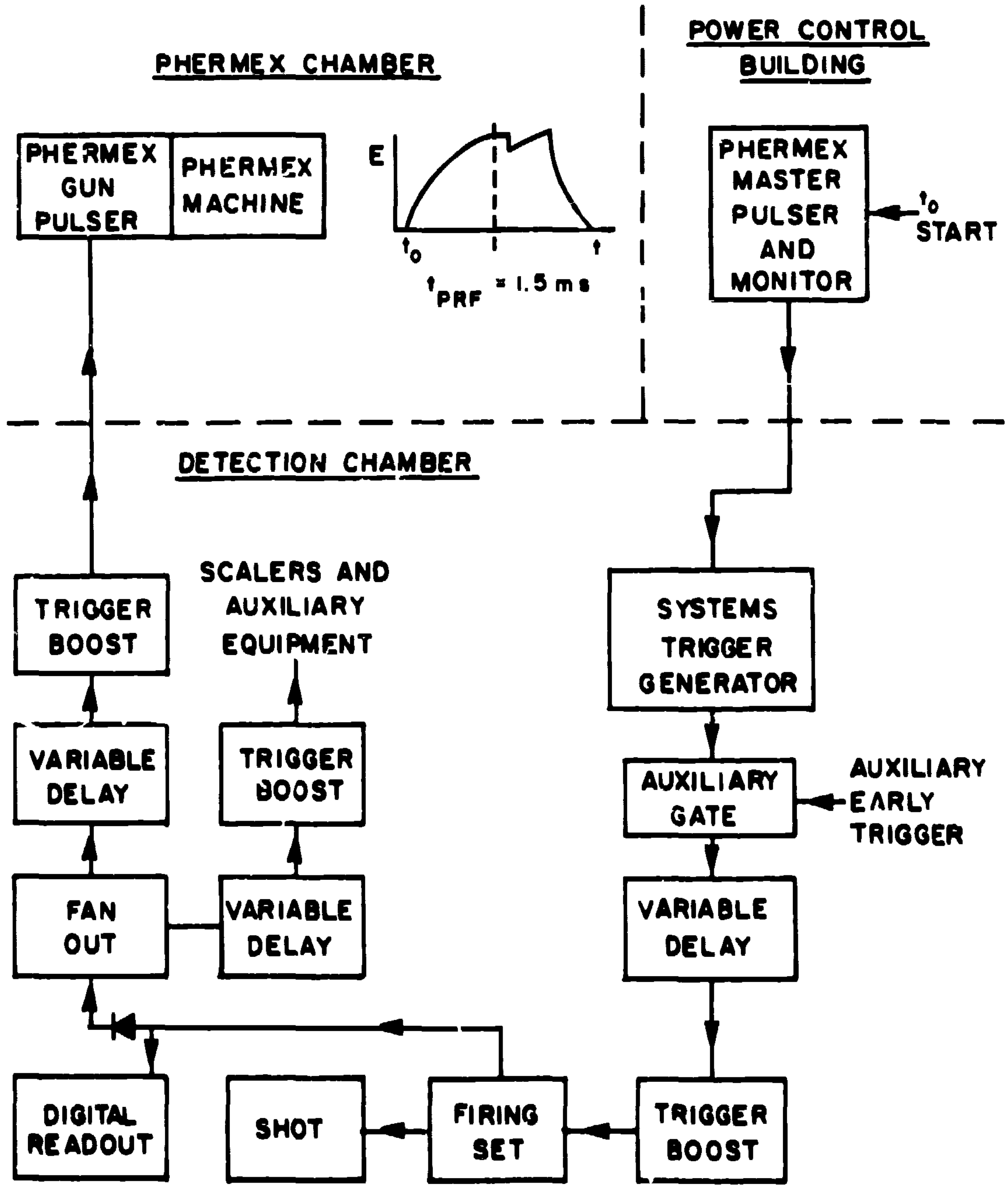


Fig. 9



PHERMEX CHAMBER
POWER CONTROL BUILDING
PHERMEX GUN PULSER
PHERMEX MACHINE
E
t_0
t
t_{PRF} = 1.5 ms
PHERMEX MASTER PULSER AND MONITOR
t_0 START
DETECTION CHAMBER
SCALERS AND AUXILIARY EQUIPMENT
TRIGGER BOOST
SYSTEMS TRIGGER GENERATOR
VARIABLE DELAY
TRIGGER BOOST
AUXILIARY GATE
AUXILIARY EARLY TRIGGER
FAN OUT
VARIABLE DELAY
VARIABLE DELAY
DIGITAL READOUT
SHOT
FIRING SET
TRIGGER BOOST

Fig. 10

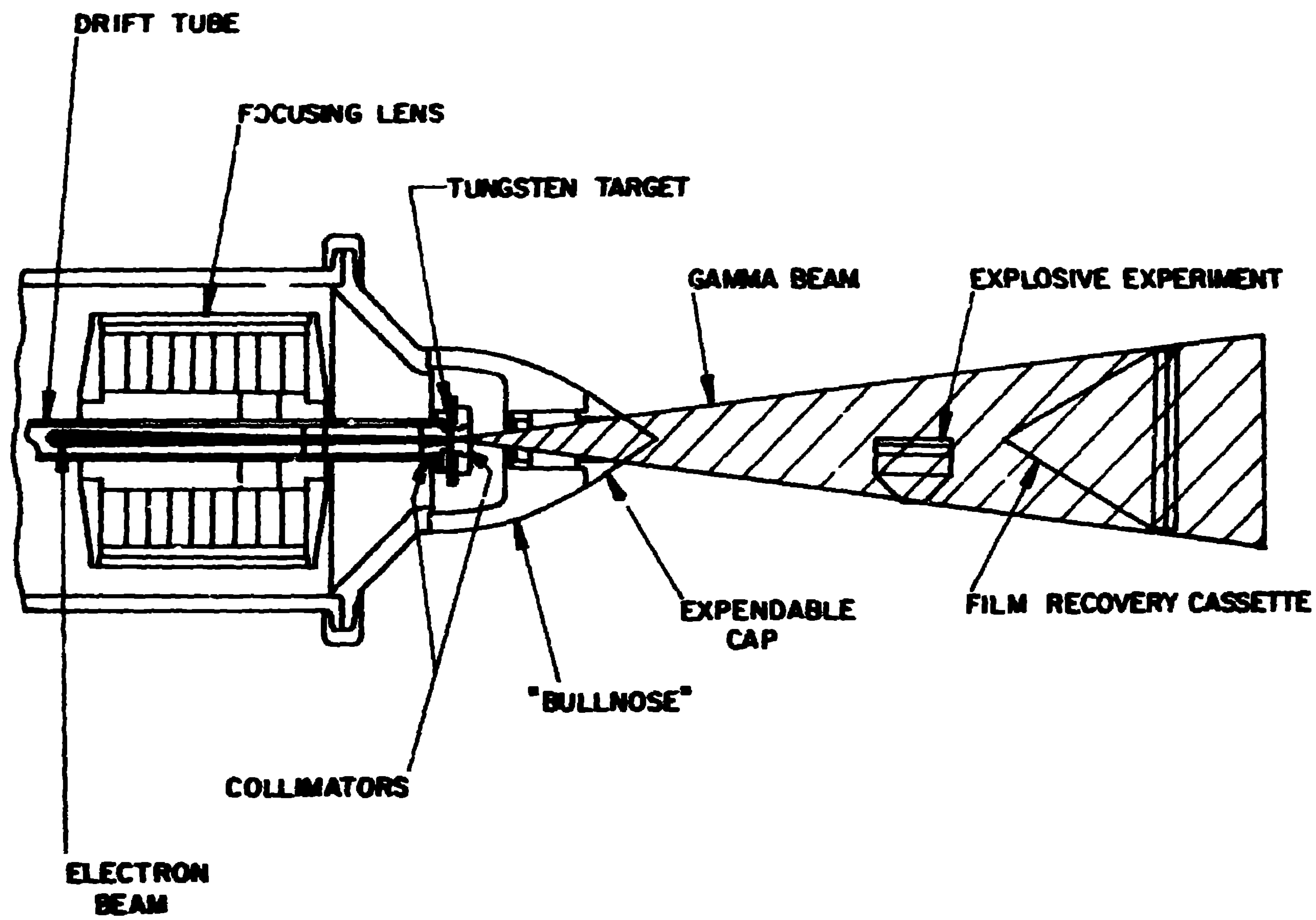

DRIFT TUBE
FOCUSING LENS
TUNGSTEN TARGET
GAMMA BEAM
EXPLOSIVE EXPERIMENT
EXPENDABLE CAP
FILM RECOVERY CASSETTE
"BULLNOSE"
COLLIMATORS
ELECTRON BEAM

Fig. 11

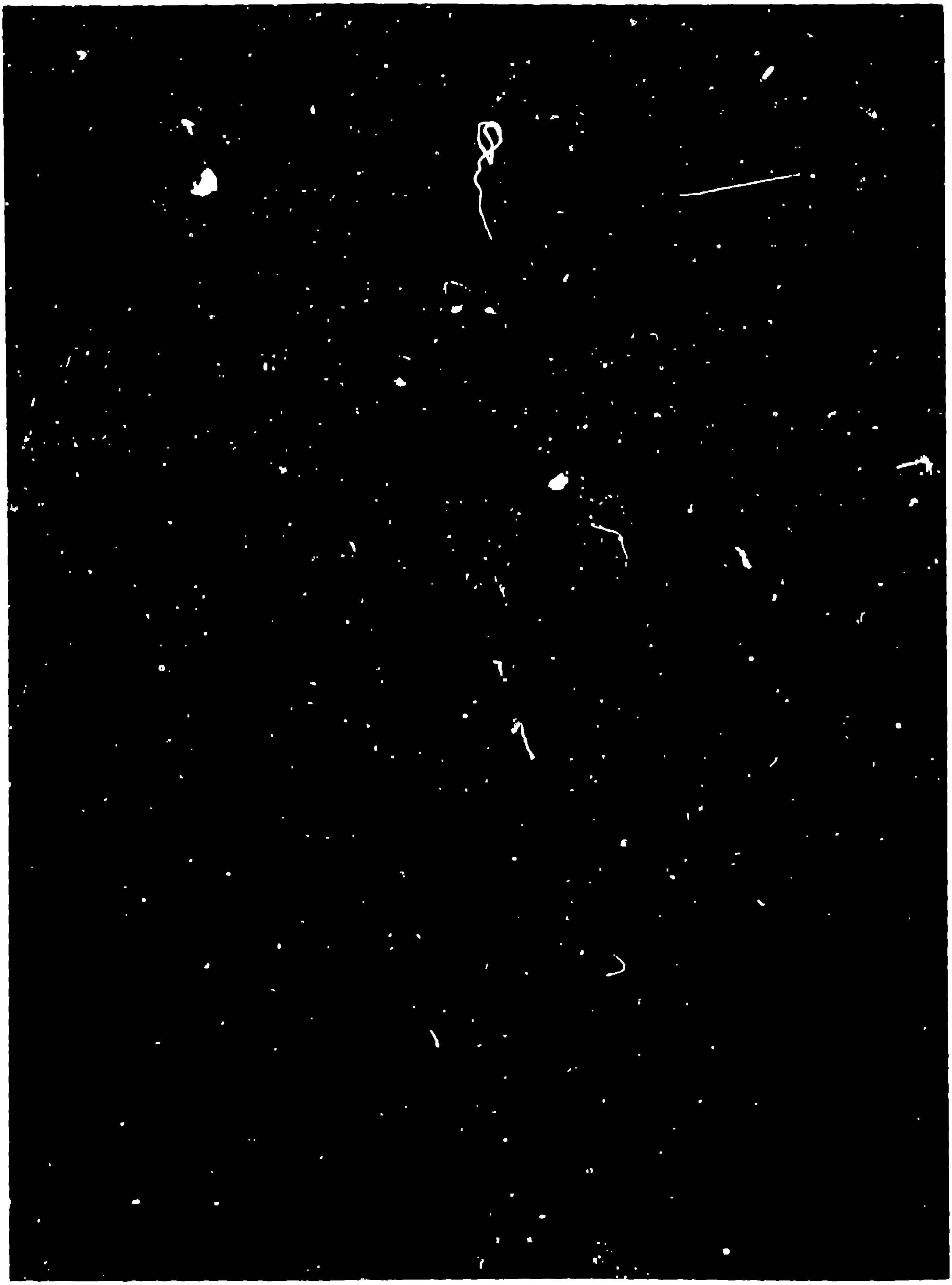


Fig. 12

	TODAY	POSTUPGRADE
MEAN ENERGY (MeV)	21	40
ACCESSIBLE ENERGY RANGE (MeV)	20-30	20-60
ENERGY DISPERSION	4%	4%
EMITTANCE (mm-mRAD)	7π	7π
TIME STRUCTURE		
MACROPULSE WIDTH (ns)	200, 100, or 40	150, 90, or 40
RISETIME (ns)	51, 37, 15	13, 13, 13
NUMBER OF MICROPULSES	10, 5, 2	7, 4, 2
MICROPULSE WIDTH (ns)	3.3 (FWHM)	3.3 (FWHM)
INTENSITY		
AVERAGE OVER MACROPULSE (A)	50 (200 ns)	90 (150 ns)
PEAK (kA)	0.30	0.60 - 0.80
ELECTRONS/MICROPULSE	6×10^{12}	1.2×10^{13}
CURRENT DENSITY (PEAK) (A/m^2)	4×10^{8}	8×10^{8}
ELECTRON DENSITY (PEAK) (e/m^3)	4×10^{18}	8×10^{18}
SPOT SIZE (DIAMETER)		
EXIT OF COLLIMATING LENS (mm)	15	15
ENTRANCE TO FOCUSING LENS (mm)	10	10
ON TARGET WITH 0.5-m FOCUS (mm)	≤ 1	≤ 1

Fig. 13

INJECTOR (HOT .)	TODAY	POSTUPGRADE
VOLTAGE (MV)	0.550	1.00 - 1.25
CURRENT (A)	350	650
PULSE WIDTH (NS)	200, 100, 40	150, 80, 40
RISETIME (NS)	50, 40, 15	13, 13, 13
RF SYNCHRONIZED	No	Yes
EMITTANCE (MM-MRAD)	$< 500\pi$	$< 500\pi$
SPOT SIZE (MM)	25	25
RF CAVITIES		
FREQUENCY (MHz)	50	50
LENGTH (M)	2.6	2.6
DIAMETER (M)	4.6	4.6
FIELD STRENGTH (MV/M)		
α	3.6	12.0
β	5.5	10.0
γ	3.4	8.0
STORED ENERGY (J)		
α	610	6800
β	1430	4700
γ	550	3000
ENERGY DEPLETION (α-CAVITY)		
ONE MICROPULSE	6%	3%
TEN MICROPULSES	30%	20%

Fig. 14

UPGRADING PROGRAMS

PHERMEX

- rf POWER INCREASE TO TRIPLE X-RAY FLUX OUTPUT
- MULTIPLE-PULSE OPERATION TO PROVIDE THREE PROGRAMMABLE X-RAY BURSTS
- OPERATIONAL UPGRADING TO HANDLE INCREASED DATA AND IMPROVED RESOLUTION

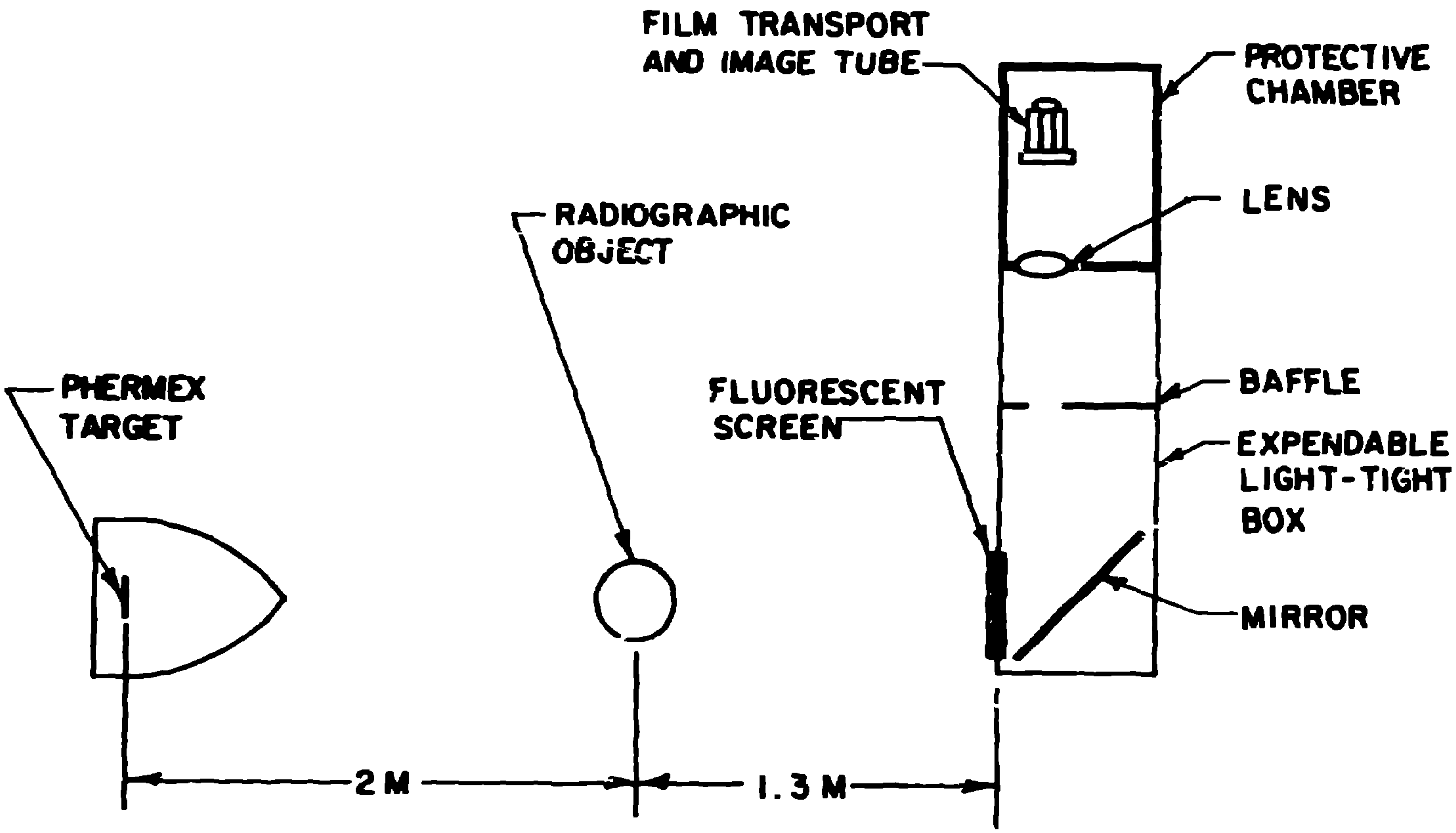
LOW VOLTAGE X-RAY UNITS

- USE OF MEVEX FLASH X-RAY UNITS ON APPROPRIATE EXPERIMENTS
- USE OF MOGUL-C FLASH X-RAY UNIT ON ROUTINE TESTS

DIAGNOSTICS

- IMPROVED RADIOGRAPHIC FILM TECHNIQUES
- ELECTRO-OPTICAL CAMERA AND FLUORESCENT SCREEN FOR MULTIPLE-PULSE OPERATION
- IMPROVED DATA ANALYSIS THROUGH INTERACTIVE COMPUTER SYSTEMS

Fig. 15



PLAN VIEW OF FLUORESCENT SCREEN / CAMERA SETUP

Fig. 16